V. "On the Chief Line in the Spectrum of the Nebulæ." By JAMES E. KEELER, Astronomer of the Lick Observatory. Communicated by WILLIAM HUGGINS, D.C.L., LL.D., F.R.S. Received March 13, 1891.

As my paper on the Motions of the Planetary Nebulæ in the Line of Sight* did not give a final determination of the exact position of the chief nebular line, and might therefore possibly be regarded as leaving in abeyance the question as to whether that line could be regarded as a remnant of the magnesium fluting, I beg to be allowed to state briefly the results of some more recent observations, which have enabled me to fix with great accuracy the true position of the chief nebular line.

At the time when my paper on the motions of the nebulæ was printed, I had not been able to obtain any satisfactory comparisons of the third nebular line with terrestrial hydrogen, all the nebulæ in my list having proved to be too faint for the purpose. I was, therefore, compelled to adopt the mean position of the principal line for the ten nebulæ observed as the normal position from which to measure displacements, and it was for the reason that the ten nebulæ did not have the uniform distribution in the sky which was desirable that the numerical results for their motions were stated as "not to be regarded as final."

In October, 1890, when the Orion nebula came within reach of the telescope, comparisons of the third line with the Hβ line of hydrogen were made without difficulty, and on the same nights the position of the principal line was determined. One such double observation, if perfect, completely solves the problem, since the displacement of the third line gives the necessary correction to the position of the first. The only question is in regard to the accuracy of the observations.

It is evident from what has already been written on this subject by Dr. and Mrs. Huggins, Professor Lockyer, and myself, that the answer to the question whether the chief nebular line is coincident with the edge of the magnesium fluting at λ 5006·4 depends upon very small differences of position, differences which would, in fact, be considered small even in solar spectroscopy. But their minuteness, although it increases the practical difficulty of observation, does not detract from their importance, since absolute coincidence of spectral lines is necessary (although not always sufficient) to establish a claim to identity of origin. It is therefore necessary to determine from a careful consideration of the Lick Observatory measures whether they are of a sufficiently high

* 'Publications of the Astronomical Society of the Pacific,' No. 11, p. 265.

order of accuracy to prove that the small observed interval between the nebular line and the magnesium fluting is real, and not due to errors of observation.

A detailed account of all the tests to which the apparatus was subjected cannot be given here. Nothing that suggested itself was omitted. The best tests, however, both for constant and for accidental errors, are afforded by observations of the motion in the line of sight of bodies whose motion is already known. As an example of such observations, I may refer to the measures of the motion of Venus in the line of sight given in the table on p. 270, 'Publications of the Astronomical Society of the Pacific,' No. 11, in which the greatest error is one English mile per second. Similar measures of the displacement of lines in the lunar spectrum were seldom in error by more than two miles, and measures of the motion of α-Tauri and α-Orionis, usually made on the same nights that the nebula was observed, were of the same order of accuracy, as determined by their agreement with each other, and with the photographic results of Professor Vogel.

In work of this character the periodic shifting of lines in the spectra of the stars and nebulæ due to the earth's annual motion is of a magnitude not to be neglected, and it should appear in the comparison of observations made at different seasons. So faithfully is the orbital motion of the earth reflected in my observations on the nebula of Orion, that I would with some confidence undertake to determine the month of the year, by measuring the distance of the principal line from the lead line used in the comparison spectrum.

With these remarks on the degree of accuracy which characterises the observations, I give below the results which have been obtained, up to the present time, for the nebula of Orion.

From sixteen complete measures, made on eleven different nights (two of which were in the winter of 1889–90), the wave-length of the principal line, corrected for orbital motion of the earth, is λ 5006·22 $\pm$ 0·014, the probable error corresponding to an uncertainty of 0·5 mile per second in the line of sight. When two measures were made on the same night, they were always in different spectra of the grating.

Ten comparisons of the third nebular line with terrestrial hydrogen were made on seven nights in 1890–91, showing, when corrected for the orbital motion of the earth, a displacement of the nebular line toward the red of 0·28 $\pm$ 0·026 tenth-metres. This corresponds to a motion of recession of the nebula from the sun of 10·7 $\pm$ 1·0 miles per second.

In recent comparisons of hydrogen with the third nebular line, I have not been able to attain the small probable error of $1\frac{1}{2}$ miles per second for a single evening's comparison, given in my letter to the

'Observatory,' as the first comparisons were made under exceptionally favourable conditions. Some small improvements in the apparatus make it probable, however, that it can be reached in the future.

Examination of the individual results for each night's work shows that the errors are purely accidental; hence, the mean of the results for the third line will be used to determine a correction to the mean of the results for the first line.

A displacement of the third line toward the red of 0·28 tenth-metre corresponds to a displacement of the principal line, in the same direction, of 0·29 tenth-metre, which is the amount by which the principal line is seen to be too near the red end of the spectrum, on account of the recession of the nebula from the sun.

Hence the wave-length of the principal line, if determined by an observer at rest relatively to the nebula, would be λ 5005·93, and this, therefore, is the *normal position* of the chief nebular line, according to all the observations of the nebula of Orion which have been made, up to the present time, at the Lick Observatory. The probable error of this result is, by the theory of least squares, 0·03 tenth-metre. The position of the MgO fluting, on the same scale, is λ 5006·36 or 0·43 tenth-metre below the normal position of the nebular line. An interval of this magnitude is not only measurable with my apparatus, but noticeable at a glance in the telescope.

An incident which occurred during the course of the work may be mentioned here, as showing how much greater the above-stated interval is than any error which could be made under good conditions of observation. The measures of January 26, 1891, on being reduced the next morning, made the interval between the nebular and lead lines 0·15 tenth-metre greater than it should have been according to previous measures. This difference led me at once to infer that something was wrong with the apparatus, and on examining the instrument I found that the observing telescope was set to a reading 5° different from the usual one, in such a direction that a higher dispersion than usual had been employed. On determining the value of the micrometer for this position of the grating, and re-reducing the observations, the discrepancy was then but a few hundredths of a tenth-metre.

In the 'Journal of the British Astronomical Association,' Mr. Maunder says, in reference to the possibility of my having over-measured the interval between the chief nebular line and the edge of the magnesium fluting, "Further, some allowance must be made for the difficulty of comparing a line with a fluting; we ought certainly not to measure from the centre of the nebular line to the extreme edge of the fluting. This will apply a small, but a further, correction in the same direction." Mr. Maunder's criticism does not, however,

apply to my own observations, which were made with this difficulty in view. If the distance between the line and the edge of the fluting could be measured with a slit-width vanishingly small, the true interval would be obtained. With a practicable slit-width, the position of the centre of the line is unchanged, but the edge of the fluting is shifted toward the red by half the width of the line. In my observations of nebulæ, the slit-width used was such as to make the bright, sharp lead line (and hence, also, the nebular line) just the width of the coarse micrometer wire (about 0·4 tenth-metre). The bright lines were observed by occulting them with the wire, the observations thus referring to their centres, but the magnesium fluting was observed by bringing its extreme edge and the *lower* edge of the micrometer wire into coincidence, the centre of the wire falling therefore upon the edge of the fluting with infinitely narrow slit. Measures of the interval between the lead line and the edge of the magnesium fluting, made with the fine micrometer wire and as narrow a slit as could be used, gave the same value as measures made in the manner just described.* The correction mentioned by Mr. Maunder is therefore unnecessary.

It appears to me, from what has been shown above, that the non-coincidence of the chief nebular line and the magnesium fluting must be regarded as proved.

In regard to the character of the line, recent observations at Mount Hamilton have shown nothing which does not confirm the opinion I have already expressed,† that under no circumstances of observation does the line tend to assume the aspect of the remnant of a fluting.

The observations which have been made at Mount Hamilton demonstrate the incorrectness of the view that the chief nebular line is in any way connected with the magnesium fluting at λ 5006·36, for reasons which may be briefly summarised as follows :—

(1). The nebular line is 0·43 tenth-metre more refrangible than the lower edge of the magnesium fluting.

(2). The nebular line has no resemblance to a fluting.

(3). Flutings and lines of magnesium, which could not fail to

* I may call attention to the fact that my own value of this interval (1·86 tenth-metres) is 0·04 tenth-metre *smaller* than the most reliable measures which have yet been published.

† "A single prism of 60° was first employed, then a compound prism of about three and one-half times the dispersion of the latter, and finally a Rowland grating of 14,438 lines to the inch. With all these different degrees of dispersion, and also with other spectroscopes employed, the nebular lines appeared to be perfect monochromatic images of the slit, widening when the slit was widened and narrowing to excessively fine, sharp lines when it was closed up. The brightest line showed no tendency to assume the aspect of a 'remnant of a fluting' under any circumstances of observation."—'Publications of the Astronomical Society of the Pacific,' No. 11, p. 266 and 280.

appear at the same time with the fluting at λ 5006,36, are entirely absent in nebular spectra.

Additional reasons have been given by Professors Liveing and Dewar, and by others who have investigated the subject, but I wish to consider here only such observations as have been made at the Lick Observatory.

The Society then adjourned over the Easter Recess to Thursday, April 9th.

Presents, March 19, 1891.

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